88-Inch Cyclotron Operations Overview

C.M. Lyneis

Introduction

The 88-Inch Cyclotron is operated as a national facility in support of U.S. Department of Energy programs in basic nuclear science. The central component is a sector-focused, variable-energy cyclotron that can be fed by either of two Electron Cyclotron Resonance (ECR) ion sources. This versatile combination produces heavy-ion beams of elements throughout the periodic table. For helium to oxygen, beam energies are up to 32.5 MeV/nucleon; for heavier ions the maximum energy per nucleon decreases with increasing mass. Typical ions and maximum energy (MeV/nucleon) are argon (23), krypton (14), xenon (8) and bismuth (5). Most metallic ions and all gaseous ions up to mass 170 have either been accelerated or can be developed as needed, with energies high enough for nuclear physics studies. High intensity light ions - p, d, ^{3}He and ^{4}He - are produced up to total energies of 55, 65, 135, and 130 MeV, respectively.

Accelerator Use

The demand for beam time at the 88-Inch Cyclotron increased dramatically in FY00, a trend which is continuing into FY01. The 8p Spectrometer ran through the first quarter of FY00 for nuclear structure experiments, then was dismantled to make way for the return of Gammasphere. Gammasphere began operation in July and is being utilized at full capacity for both on-line and off-line experiments. The Berkeley Gas-Filled Separator (BGS) ran a large amount of hours in FY00 for experiments designed to better characterize the device in preparation for confirmation experiments of Element 118 and searches for Element 119 in FY01. The BEARS project has been concentrating on developing a ^{14}O beam, which should be ready sometime in FY01. Meanwhile experiments continue using 11C. The research time (beam on target) in FY00 was 4333 hours, a decrease of 4% from FY99 levels. This was due primarily to an increase of almost a factor of two in the number of hours lost to machine failure; some of which can be attributed to increased stresses on the cyclotron while running high intensity heavy ions for the BGS program. The Accelerator Operation Summary (Table 1) shows that in FY00 67% of the calendar year was scheduled. Of this, 73% was used for research (beam on target) while the remaining time was divided between tuning (13%), machine studies (5%), and unscheduled maintenance (9%).

Nuclear science research accounted for 3266 research hours, applied research for 719 hours, high energy, space and materials sciences for 281 hours, and biology for 67 hours. 79% of the nuclear science research utilized one of the four major facilities in operation: the 8p Spectrometer and Gammasphere combined for 29%, BGS for 47% and BEARS for 3%. The nuclear science research can be broken down into nuclear structure (32%), heavy elements and chemistry (43%), exotic nuclei (9%), reactions (5%), astrophysics (2%) and weak interactions (9%). The applied research - in partnership with both U.S. and foreign industries, small business, and government laboratories - consisted primarily of radiation effects testing for space applications using either the proton or heavy ion irradiation facility. The applied research for high energy physics was done in support of the development of detectors and associated electronics for the ATLAS detector at LHC. Some materials science work was also performed to support of the study of radiation damage in semiconductor materials by the Center for Advanced Materials at LBNL. The biology research was done in support of the NASA NSCORT program as well as some NIH programs.

Ions, Energies and Intensities

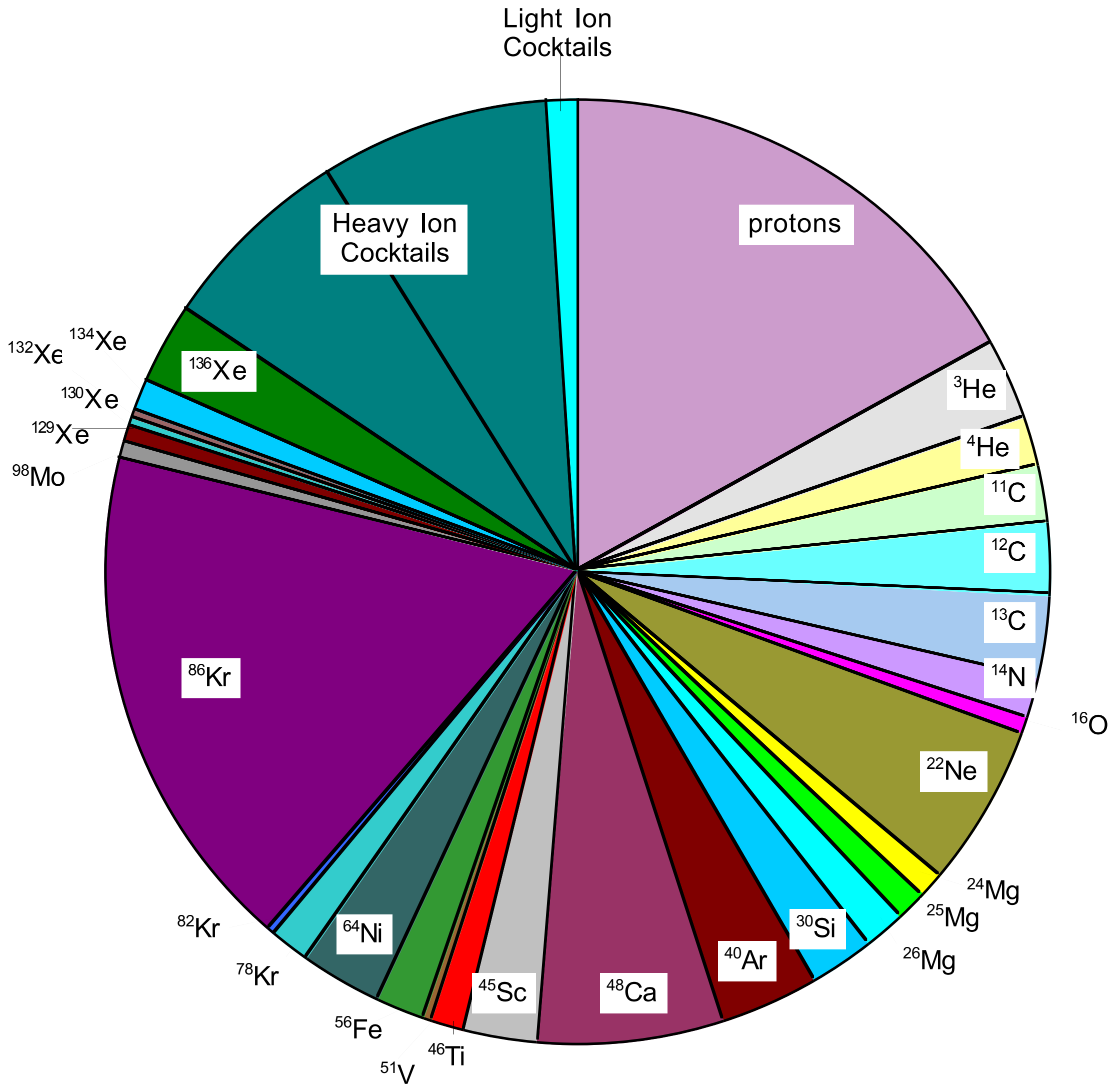
The cyclotron fed by its ECR sources provides a wide range of ions, energies, and intensities and most elements can be accelerated. To date, 48 elements have been accelerated including every element from hydrogen to zinc. The heaviest element accelerated is uranium. A total of 98 isotopes have been accelerated - recent additions are ^{43}Ca, ^{87}Rb, ^{94}Zr, ^{97,98,100}Mo and ^{127}I. Many ions has been run using isotopically enriched source materials including, ^{3}He, ^{13}C, ^{15}N, ^{18}O, ^{21,22}Ne, ^{33,34,36}S, ^{44,48}Ca, ^{64}Ni, ^{70}Ge, ^{78,86}Kr, ^{96}Zr, ^{136}Xe and ^{154}Sm. The older LBL ECR is currently undergoing an upgrade which includes new stronger sextupole magnets, higher performance solenoid magnets made available when the AECR was upgraded, and a new aluminum sextupole housing. This upgrade will be completed in February 01 and will provide improved high charge state production and more stable operation.

Figure 1 gives the breakdown of beams run in FY00 for the overall program plus the two major components of nuclear structure and BGS. At the present time, the 88-Inch Cyclotron is the only U.S. accelerator capable of generating the several hundred particle-nanoamp beams of ^{86}Kr necessary for the experiments on Element 118 and searches for Element 119 projected to take place towards the end of FY01. Calculations show that even heavier beams - such as ^{136}Xe - may prove useful in cold fusion searches for even heavier elements. We are working towards improving the intensity of these heavy beams by upgrading the ion sources and injection line.

VENUS

VENUS, a 3rd generation Electron Cyclotron Resonance ion source, which has a very high magnetic field produced by superconducting coils is under construction. It will boost the maximum energies and intensities for heavy ions from the cyclotron particularly for ions with mass 60 and above. VENUS will also serve as a prototype for the RIA ECR and provide data on the intensity, charge state distributions and emittance of beams such as bismuth and uranium, which are the most challenging for the RIA project. VENUS is designed to operate at frequencies up to 28 GHz, twice the frequency of the LBNL AECR-U. The VENUS superconducting magnets have already operated at fields for optimum 28 GHz operation. Since plasma densities and extracted currents scale with the square of the microwave frequency, the best performance will be obtained at 28 GHz, which can be provided by a 10 kW 28 GHz gyrotron.

FY00 - Beams



Construction of VENUS is proceeding at a rapid rate. The superconducting magnets are complete and tested. Construction of other major components including the cryostat, plasma chamber, injection and extraction sections are well along and expected to be completed this spring. The site preparation is complete and ready for the installation. Cool down of the cryostat and magnets is scheduled for summer 01 and the first testing of the source is scheduled for the fall of 01 using a 2 kW 18 GHz klystron.

Radioactive Beam Technology

The 88 Operations group is collaborating on two projects which involve the production, transportation and ionization of radioactive atoms. In both projects, ECR ion sources are used to efficiently ionize radioactive atoms prior to further acceleration. This is both important for development of new scientific opportunities at the Cyclotron and to further the technologies critical for the Rare Isotope Accelerator (RIA) being proposed as the next major nuclear science facility.

The BEARS project is described in the Heavy Ion Research Section. The transfer line between the two cyclotrons was completed in FY99 and in FY00 it was used to produce ^{11}C beams with intensities up to $2x10^8$ pps. Three nuclear science experiments were completed successfully with the radioactive carbon beams.

The goal of the second project, the 14O experiment, is to produce this short-lived isotope using the cyclotron, transport it through a vacuum line as CO to an ion source where it will be ionized and accelerated to 30 kV and then implanted to provide an ^{14}O source for beta shape spectrum measurements. A test stand has been completed using an ECR ion source, IRIS (Ion Source for Radioactive Isotopes) and during the last year $^{14}O^{1+}$ beams at an average intensity of $2x10^7$ pps have been achieved which is a sufficient rate to performed the beta shape spectrum experiment.

Table 1
Accelerator Operation Summary - FY00

Accelerator Operation Summary (hours)	
Research	4333
Tuning	767
Machine Studies	307
Unscheduled Shutdowns	509
Scheduled Shutdowns	2868
Electrical Energy Consumption (GWH)	5.3
Cost of Electrical Energy	
(Thousands of Dollars)	387
Experiment Summary	
Beam Utilization for Research (Hours)	
Nuclear Research	3266
Atomic Physics	0
Biology and Medicine	67
High Energy Physics	281
Applied Research (recharge)	719
Total	4333
Nuclear Science Research	
Number of Nuclear Science Experiments	61
Number of Scientists Participating	107
Number of Students	34
Institutions Represented	
Universities	13
DOE National Laboratories	4
Foreign Institutions	19
Other government labs	0
Non-nuclear Science Research	
Number of scientists and engineers	86
Number of students	4
Institutions and Companies	28
Total users (all research)	231
Percentage of Beam Time (all research)	
In-House Staff	55.7
Universities	10.9
DOE/Government Laboratories	13.9
Industry	2.7
Foreign Institutions	16.8